PENNSTATE ARL

iMAST

Institute for Manufacturing and Sustainment Technologies

QUARTERLY 1999 No.2

A U.S. Navy Manufacturing Technology Center of Excellence

iMAST Participates in Tech Trends 2000

Navy ManTech and iMAST recently participated in Tech Trends 2000, a Mid-Atlantic consortia of industry, academia, and government. The event was presented by Representative Curt Weldon (R. PA) and the National Defense Industrial Association and it was held at the downtown Philadelphia Convention Center. Penn State's Applied Research Laboratory helped sponsor the event in order to provide a focused look into future collaboration and funding opportunities from the perspective of organizations and individuals working R&D issues throughout Pennsylvania, New Jersey, Delaware, and Maryland. In setting up this event, Congressman Weldon, who serves on the House Science Subcommittee for Technology, noted: "This is the first time key public and private leaders have gotten together to discuss federally funded research and development for the next millennium. If you want to be a key player in R&D for the next 20 years, you could not afford to miss this conference."

Dr. Ray Hettche (left), Director of Penn State's Applied Research Laboratory discusses technology issues with the Honorable Jacques Gansler (right), Under Secretary of Defense for Acquisition and Technology. Congressman Curt Weldon (center) listens in on the discussion.

Key speakers for the conference included Congressman Weldon, The Honorable John Hamre (Deputy Secretary of Defense), and The Honorable Jacques Gansler (Under Secretary of Defense for Acquisition and Technology). An impressive technology panel was composed of Dr. F. L. Fernandez (Director, Defense Advanced Research Projects Agency); Dr. Ralph Amado (Vice Provost for Research and Development, University of Pennsylvania); Dr. Joseph Bordogna (Acting Director, National Science Foundation); Dr. Bruce Tarter (Lawrence Livermore National Laboratory); and Mr. Sherman McCorkal (President and CEO, Technology Ventures Corporation). These individuals provided an insightful look at future R&D as we move into a new century and millennium.

The Applied Research Laboratory provided an exhibit portraying its science and technology base, which includes iMAST's Navy ManTech efforts. ARL's naval presence was joined by the Office of Naval Research Navy ManTech Program directorate, as well as Naval Sea and Air Systems Command representatives. Manufacturing and dual-use technologies were highlighted in several structured breakout sessions.

Tech Trends 2000 was a success. The objective of building a four-state virtual partnership or "smart region" got off to an excellent start. The synergy developed in bringing government, industry, and academia together as a team allowed a focus of energy and effort towards meeting the challenges and opportunities that manufacturing technology brings to the future. And that is a principal mission of Navy ManTech.

FOCUS ON MATERIALS SCIENCE TECHNOLOGIES

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IN THIS QUARTERLY

DIRECTOR'S CORNER

Changes on the Horizon

It's hard to believe that we have less than three months remaining in fiscal year 1999.

In this issue of our iMAST newsletter we are featuring the Materials Science Division of ARL. Another one of our best and brightest, Dr. Tim Eden, has provided us with an article on spray metal forming. This unique technology promises to provide some unique manufacturing opportunities through the development of high-temperature, high-strength aluminum alloys. Within this division, Dr. Maurice Amateau and his colleagues are doing many exciting things, including a manufacturing process called cold gas dynamic spraying (CGDS). Like the electron beam-physical vapor deposition (EB-PVD) process, which was featured last year in one of our newsletter issues, cold gas dynamic spraying technology is from the former Soviet Union. We are investigating applications of this technology for the Department of Defense as well as the private sector. We will provide a feature article on this particular technology in our next newsletter, which focuses on the Materials Science Division.

At ARL, we are proud of the relationships we have with the other Navy ManTech Centers of Excellence. To that end, we try to have joint activities with all centers whenever possible. For instance, we provide subject matter experts to help the Best Manufacturing Practices (BMP) Center conduct surveys throughout the country. Interestingly enough, iMAST recently became the focus of one of these surveys for identifying best manufacturing practices. I am pleased to report that the survey team found approximately 50 best practices associated with our core technologies. Their report will be published shortly. You will be able to find it on the BMP home page at: www.bmpcoe.org. We will also receive numerous hard copies of the report, once it is published, and will announce such in a subsequent newsletter. We also plan to have several copies available at our booth during early December at the Defense Manufacturing Conference '99, which will be held in Miami, Florida. So if you are there, please stop by and pick up a copy. We hope to see many of you there.

We have had a busy quarter. In addition to our work at the laboratory, we have many of our staff on the road attending and participating in conferences, visiting or hosting industry, or manning expo booths at events such as Navy League Symposiums or the annual American Helicopter Society Forum to foster the transfer of Navy ManTech technologies.

As always, I look forward to your feedback. Please feel free to contact me or any of my staff if you have any questions or challenges we can address. Thank you.

Henry Watson

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MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES | MATERIALS SCIENCE TECHNOLOGIES | HIGH-ENERGY PROCESSING TECHNOLOGIES | NAVY/MARINE CORPS REPAIR TECHNOLOGIES

FEATURE ARTICLE

Focus on Materials Science Technologies

Aluminum Alloys Produced by Spray Metal Forming

by Timothy J. Eden, Ph.D.

The Department of Defense (DoD) and industry have placed emphasis on the production of materials that are lighter and cheaper, but also have higher performance.

The Applied Research Laboratory at Penn State is currently developing advanced materials processes that addresses the manufacture of low-cost, lightweight, high-performance materials. Spray metal forming has emerged as a viable process for producing unique materials. To meet stated DoD and industry objectives, ARL's Material Science Division has established a spray metal forming facility that specializes in aluminum alloys. Spray-formed billets are now being produced on a routine basis. These billets are combined, in the downstream manufacturing process, with extrusion or forging, and then coupled with high-speed machining to produce components in final form.

Spray metal forming is a rapid solidification technology for producing semi-finished tubes, billets, plates, and simple forms in a single integrated operation. The most widely used spray metal process is patented by Osprey Metals Ltd., Neath, Wales.[1] Spray forming involves converting a molten metal stream into a spray of droplets by high-pressure gas atomization (Figure 1). The droplets cool rapidly in flight and ideally arrive at a collector plate with just enough liquid content to spread and completely wet the surface. The metal then solidifies into an almost fully dense preform with a very fine, uniform microstructure. Steel, copper, nickel-based superalloys, and aluminum alloys have been successfully spray formed.

A schematic of the spray forming plant at ARL Penn State is shown in Figure 2. Metal is placed in a crucible and heated to the desired temperature under an inert atmosphere, usually argon or nitrogen. The spray chamber is purged with nitrogen until there is a very low level of oxygen present. A stopper rod is lifted and the metal stream flows through the nozzle in the bottom of the crucible. Pressure in the crucible is increased to maintain a constant metal flowrate. High-pressure nitrogen jets at near-sonic velocity atomize the molten stream and carry it toward the collector plate. The collector plate is placed on a ram that rotates and withdraws so that the buildup of the billet is uniform and the spray height or distance the metal droplets travel is the same during the entire spray forming operation. This ensures the microstructure and the precipitates are uniform in size and distribution throughout the entire billet. It is also possible to inject particulate reinforcement such as silicon-carbide (SiC) into the atomized metal spray. These particles are deposited with the molten metal on the surface of the billet to produce a metal matrix composite (MMC) with a uniform distribution of the particulate. See Figure 3.

Process variables are closely controlled to produce the desired cooling rate and microstructure. These include the gas-to-metal (G/M) ratio, commonly defined as cubic meters of gas per kilogram of metal, the pour temperature, spray height or metal droplet flight distance, and metal flowrate. These variables are adjusted to optimize the desired properties and to reduce production costs.

Rapid solidification processes such as spray metal forming offer some distinct advantages over conventional ingot metallurgy processing. Superior properties due to fine grain

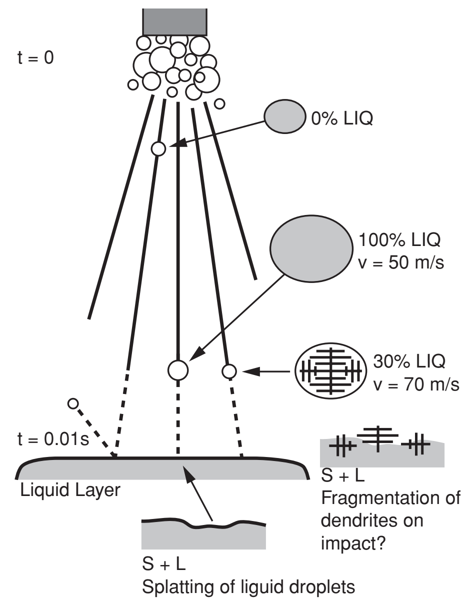

Figure 1. Atomization and deposition process for spray metal forming.

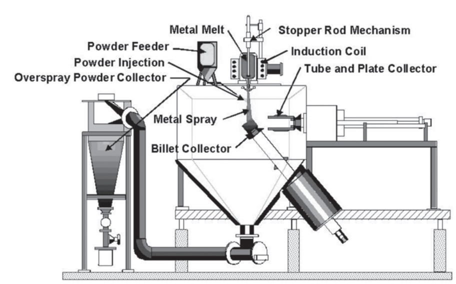

Figure 2. Spray Forming Facility Schematic.

PROFILE

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Dr. Eden's research interests include spray metal forming, cold gas dynamics, multiphase heat transfer and fluid flow, process control and optimization, and thermodynamics. He can be reached at (814) 865-5880, or by e-mail at: <tje1@psu.edu>.

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sizes; a fine, homogeneous distribution of second phase precipitates; and the absence of macrosegregation result from cooling rates on the order of 10^3 to 10^5 K/s (although not as high as other rapid solidification processes; e.g. gas atomization processes approach 10^6 K/s).[2] The higher range in cooling rate in spray forming is obtained by higher G/M ratios. In certain alloy systems, a high volume fraction of fine (0.05 to 0.2 µm) intermetallic dispersoids may be obtained with high G/M ratios.

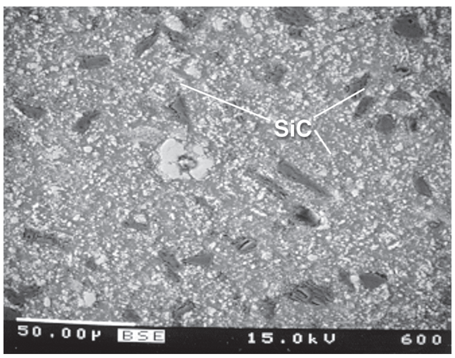

Figure 3. As-spray-formed Al-12Fe-1V-2Si alloy reinforced with 14µm SiC particulate.

Most other rapid solidification processes produce metal powders as the first step in processing. The aluminum alloy powders are atomized in air to form a thin layer of oxide to make the powders safer to handle. Subsequently, these metal powders must be sieved, classified, and consolidated in an inert atmosphere. Spray metal forming offers the distinct advantage of skipping these intermediate steps by atomizing and collecting the spray in the form of a billet in a single operation. Also, the elimination of powder handling reduces oxide content and enhances ductility.

ARL Penn State Facilities

The Penn State spray metal forming facility is a research scale plant that is capable of producing billets, plates, and tubes. The melt capacity is 145 lbs. of aluminum. Billets with diameters from 6 to 10 inches can be produced with lengths up to 16 inches. Plates can be produced that are 6 inches wide by 12 inches long with thickness up to 0.8 inches. Tube sizes range from 3 to 9 inches inside diameter with wall thickness up to 1 inch. A powder feeder may be used to inject particulate reinforcement into the gas stream near the point of atomization to form a metal matrix composite with uniform distribution of the injected particulate.

The Metals and Ceramics Processing Department has facilities to extrude rod stock from spray-formed billets, characterize microstructure by preparing and examining metallography samples, and perform hardness tests. The department's extrusion press can extrude materials up to 2 inches in diameter at temperatures up to 970°F and loads approaching 80 tons. Metallography facilities include an automatic polisher and an inverted metallograph equipped with image analysis software. Heat treating furnaces are also available within the department. Using other Penn State facilities, department personnel perform tensile, dynamic modulus, and dilatometer (coefficient of thermal expansion) tests; scanning, backscatter, and transmission electron microscopy; electron microprobe; and x-ray diffraction. In addition, a wealth of facilities and expertise are within easy access at Penn State's Materials Research Institute. When necessary, these tests can be preformed within a week to give an initial characterization of an alloy.

Many different aluminum alloys and SiC-particulate reinforced aluminum MMCs have been processed at Penn State. They include conventional alloys in the 2XXX, 3XXX, 5XXX, 6XXX, and 7XXX series; high-temperature and high-strength alloys; and high-silicon-content alloys. The non-conventional alloys have been developed specifically for spray forming or adapted from alloys developed for rapid solidification rate (RSR) processes such as gas atomization or melt spinning. These alloys have shown superior properties such as wear resistance, room- and high-temperature strength, and creep resistance. The high-temperature alloys are particularly exciting since they may be used to replace titanium components in aerospace applications.

An excellent example of the effects of spray forming can be noted in a comparison of cast B390 and a spray formed aluminum 390 alloy (Figure 4).[3] Both of these alloys are hyper-eutectic alloys containing 17% silicon. Both have similar compositions. In the as-cast B390, primary silicon comes out of solution to form very large particles distributed randomly throughout the metal. These particles make secondary processing such as forging or extrusion almost impossible and machining very difficult. In the spray-formed 390, the silicon particles are much smaller and very uniformly distributed in the metal. This allows the alloys to be extruded and gives the alloy good thermal stability. PEAK, a German company, has exploited these properties to produce cylinder lines for Diamler-Benz and is currently exploring the use of these alloys for other engine components.[4] ARL is currently performing work in the high-silicon alloys.

Spray forming has been used to increase the performance of the 7XXX alloys. Conventional alloys such as 7050 and 7055 have been spray-formed, extruded, and tested for tensile properties. Alloys developed especially for spray forming such as the ultra-high zinc content alloys developed by Pechiney, and 7050 with additional zinc have been processed. Many of these alloys have been processed with the addition of SiC to improve the stiffness. These alloys have shown superior strength properties over conventionally processed material. A summary of the results is listed in Table 1.

Ultra-High Temp. Alloy

ARL has looked at a number of ultra-high-temperature alloys that retain their useful strength at temperatures to 575°F. Many of these alloys were originally developed for processing by the comminution of planar flow cast ribbons followed by vacuum hot pressing and high-temperature deformation such as extrusion, rolling, or forging. The very high cooling rate of planar flow casting produces very fine particulate in the material that give it superior properties which may degrade during consolidation.

Table 1. Mechanical properties of spray formed 7XXX alloys in the peak-aged condition (T6).

Alloy Type	Extrusion Type	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (percent)	Elastic Modulus (msi)
7050	Full-Scale	90.0	82.1	17.4	11.2
7050+3%Zn	Full-Scale	92.3	82.4	16.0	11.4
Pech-1	Small-Scale	107.7	107.0	14.0	10.3
Pech-1	Full-Scale	96.5	94.4	10.5	11.1
Pech-1 + SiC	Full-Scale	95.3	91.6	6.1	17.1
Pech-4 + SiC	Full-Scale	95.8	86.2	4.0	16.3
Kyoto-1	Small-Scale	106.0	103.3	9.0	10.4
Kyoto-1	Full-Scale	97.7	93.6	3.9	12.2
Kyoto-1 + SiC	Full-Scale	103.6	94.9	2.6	14.8
Kyoto-2	Small-Scale	98.4	89.8	10.4	11.6

Alternative processes that are capable of producing very fine stable strengthening particles, while reducing the number of processing step and manufacturing costs and while reducing alloy contamination, are needed. ARL has shown that by using advanced spray metal forming techniques, it may be possible to achieve sufficient properties to make a number of alloys useful for high-temperature applications.

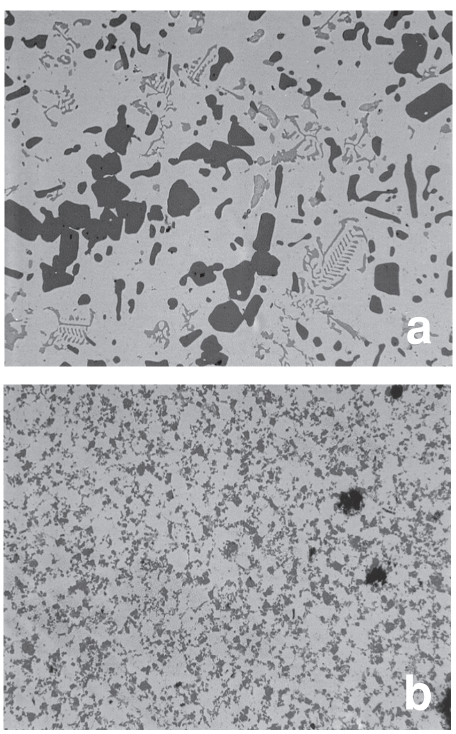

Figure 4. Light optical microscopy of B390 alloy at 200x. (a) Conventional as-cast microstructure. (b) Spray-formed microstructure.

The basis for many ultra-high-temperature alloys is the formation of very fine, thermally stable, intermetallic dispersoids that form during rapid solidification. The attainment of high-temperature strength requires dispersoids that are less than 0.1mm in size and are thermally stable to temperatures well over the intended service temperature.[5] Although many different alloys were investigated, four principal alloy systems originally developed for RSR processing have been extensively spray formed at ARL. These are Al-Fe-V-Si (FVS), Al-Fe-Ce-W (FCW), Al-Ce-Cr-Co (CCC), and Al-Ni-Co (NYC) alloys. In order to optimize mechanical properties, these alloys were spray formed over a range of processing parameters. For ultra-high temperature aluminum alloys, the melt superheat, or pour temperature, G/M ratio, and the injection of SiC particulate, have the greatest effect on microstructure (e.g., droplet and dispersoid size and volume fraction) and resultant properties.

In the FVS alloy system, pre-solidified droplets can be readily seen in the microstructure (Figure 5a). Extrusion tends to elongate these droplets in the direction of extrusion (Figure 5b). As the superheat or pour temperature was decreased, the number of pre-solidified droplets increased while their average size decreased. Figure 5c reveals that the pre-solidified droplets contain very fine dispersoids. These dispersoids were identified as $Al_{12}(FeV)_3$ using transmission electron microscopy (TEM).

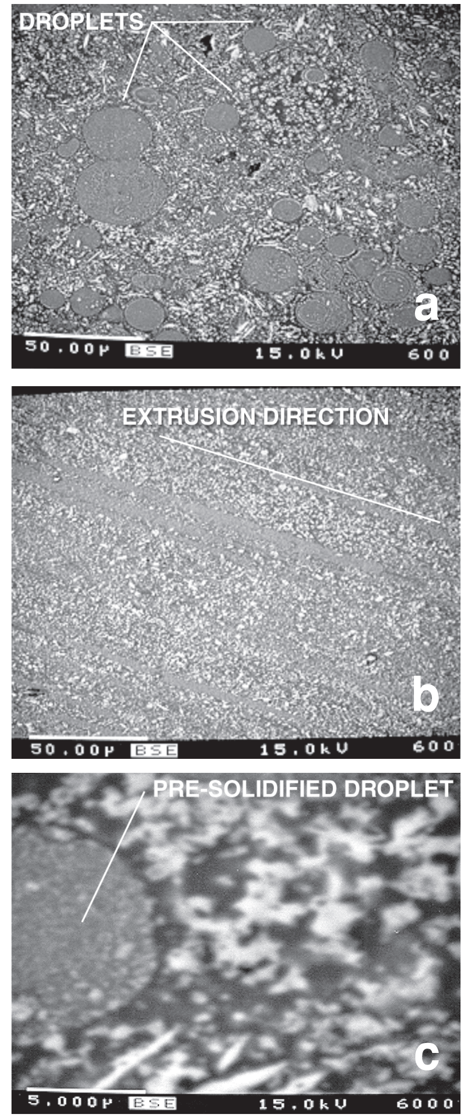

Figure 5. Back-scattered electron images of the microstructure of an Al-12Fe-1V-2Si (FVS) alloy. (a) Pre-solidified droplets can be readily seen in the microstructure. (b) Extrusion tends to elongate these droplets in the direction of extrusion. (c) Pre-solidified droplets contain very fine dispersoids of $Al_{12}(Fe,V)_3Si$.

The G/M ratio was shown to have a very pronounced effect on an alloy's resultant microstructure. Figure 6a shows the microstructure of a NYC alloys spray formed at a G/M of 6.4. At very high G/M ratios, a nearly amorphous structure was obtained in this alloy system as shown in Figure 6b where the same alloy was sprayed at a G/M of greater than ten. The occasional crystalline particles on the order of 100 nm in diameter seen in this microstructure were identified as $Al_{12}Y$ by TEM.

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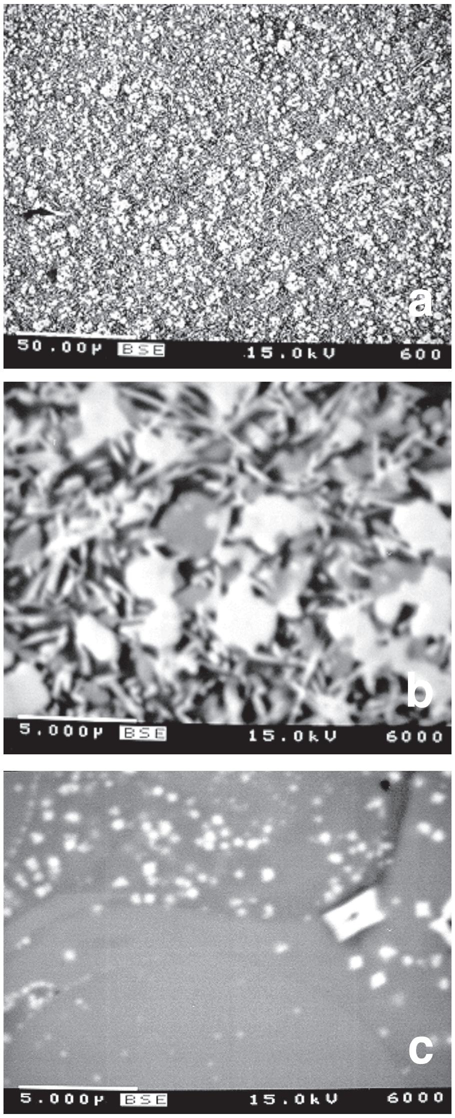

Figure 6. Back-scattered electron images of the microstructure of an Al-8.59Ni -20.82Y-3.45Co (NYC) alloy. (a) Low magnification image showing the very high volume fraction of second phase in this alloy spray formed at a G/M of 6.4. (b) High magnification image reveals the morphology of the second phase precipitates. (c) At very high G/M ratios, a nearly amorphous structure was obtained in the same alloy.

High-temperature forging of the NYC alloy has been found to further refine the microstructure as shown in Figure 7. This particular material was extruded into a 2.5-inch diameter rod from a 7-inch as-sprayed billet (extrusion ratio of 7.5) at an extrusion temperature and pressure of 900°F and 2,000 psi respectively (Figure 7a). The extruded rod was subsequently close-die forged at 965°F and 3,000 psi (Figure 7b).

Overall, the mechanical properties of spray-formed, ultra-high-temperature aluminum alloys approach those of similar alloys designed for RSR processing. A comparison of the yield strength as a function of temperature is shown in Figure 8. Spray-formed NYC alloys have achieved 10^7 cycles fatigue run-out at >26 ksi (R = –1) at 575°F and creep strains of 0.35 percent after 100 hours at 20 ksi and 450°F.

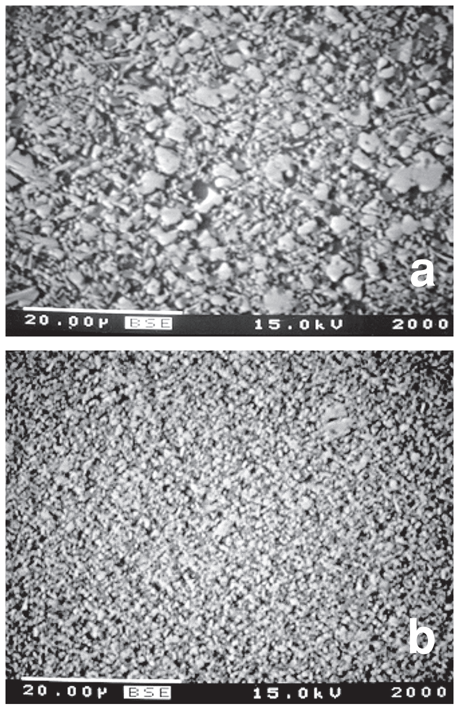

Figure 7. Back-scattered electron images of the microstructure of an extruded and forged Al-8.59Ni -20.82Y-3.45Co (NYC) alloy. (a) Material was extruded (ratio of 7.5) at an extrusion temperature and pressure of 900°F and 2,000 psi respectively. (b) Material subsequently close-die forged at 965°F and 3,000 psi. Note the microstructural refinement.

ManTech Programs

Currently there are two Navy ManTech programs at ARL that use spray-formed material to produce components for use in DoD vehicles. The first program is to produce track pins for the Advanced Amphibious Assault Vehicle (AAAV) using an ultra-high-strength aluminum alloy. The second program is to develop the spray forming processing parameters to produce an ultra-high-temperature

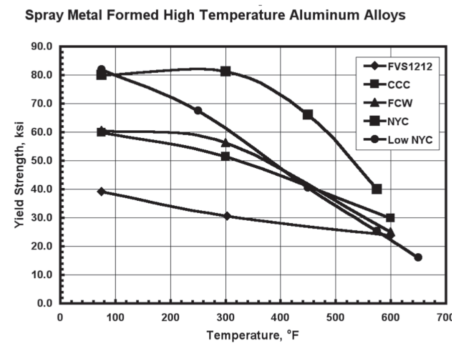

Figure 8. A comparison of the yield strength as a function of temperature of ultra-high temperature, spray formed aluminum alloys processed at ARL Penn State.

aluminum alloy for stator vanes in the Joint Strike Fighter (JSF) engine.

The goal of the track pin program is to develop processing that produces an ultra-high-strength aluminum alloy that can replace the steel currently used in the manufactured pins for the AAAV. The objective is to replace the hollow steel pin with a solid aluminum pin that has similar properties (see Figure 9). Several alloys were spray-formed, extruded, heat-treated, and tested to determine the tensile strength, ductility, and modulus. The two alloys with the best combination of properties were selected for additional processing. To increase the stiffness, SiC was added during spray forming. The spray formed ultra-high-strength alloys have yield strengths in excess of 100 ksi and show good ductility even with the addition of SiC. Track pins have been produced and are in being tested. The corrosion resistance of these materials is currently being tested. Preliminary results indicate that the corrosion resistance of these alloys is improved by spray forming. The use of

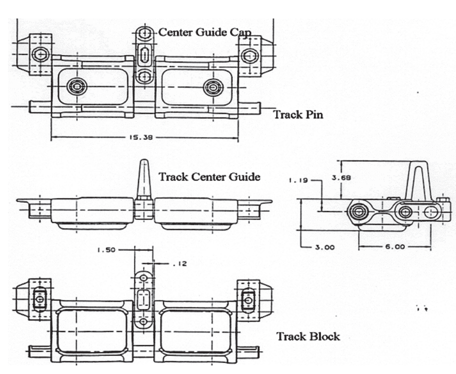

Figure 9. Ultra-high-strength aluminum track pins for use on the AAAV tread.

the ultra-high-strength aluminum would result in a weight reduction of over 450 lbs.

JSF Stator Vanes

The NYC alloy shows promise for use in static parts of jet engines. The material properties at high temperatures provide an opportunity to replace heavier titanium parts with a lighter-weight aluminum alloy resulting in substantial saving in life-cycle costs. The ManTech program will produce high-temperature aluminum alloys via spray forming and will develop the most economical processes to produce finished components.

ARL has produced the high-temperature aluminum alloy and is working with extrusion, forging, and machining contractors to develop the most efficient and economical processes to deliver a finished part. The alloy has been extruded and machined into the final component configuration. The alloy has good machining characteristics. Forging trials have shown that the material can be readily deformed. Forging offers increased material yield.

Semi-Solid Forming

Another manufacturing process that shows promise for producing economical parts is semi-solid forming. The process involves heating the alloy to a semi-molten state and then pressing the slug into a die. For the metal to properly fill the die, it must be heated until the particles become spherical. As a result of the spray forming process, the particles are spherical. This greatly reduces the heating time and lowers the potential for grain growth. The spray-formed metal in the semi-solid state has excellent flow characteristics. A lower force is required to fill the die. The metal flows more uniformly resulting in improved yields. Semi-solid formed parts made with spray formed material are shown in Figure 10.

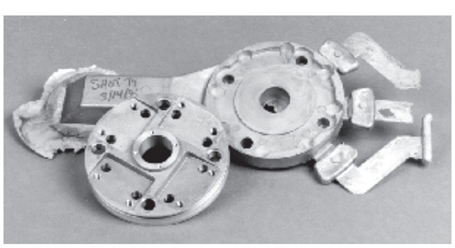

Figure 10. Semi-solid formed components made with a spray-formed aluminum alloy.

Processing Modeling

Process models for spray forming have been developed in the department. Complete numerical and physical models of the spray forming process are available to aid in the optimization of process parameters. The numerical model of the spray process uses a Eulerian-Lagrangian approach. The gas is treated as a continuous phase in an Eulerian framework involving the Navier-Stokes equations. The droplets are treated as a discrete phase using single particle dynamics. Statistics are generated from the discrete phase by computing a large sample of particle trajectories in the force field due to the gas phase. Models are used in the discrete phase for particle drag, heat transfer, and agglomeration. The droplet transport model provides a description of size distribution, density distribution, trajectory, kinetic energy and temperature. With this information the model can be used to help determine the optimum spray parameters for a number of different alloys.

A phase doppler anemometer (PDA) system has been set up to complement the modeling effort. The PDA system provides information about the atomization of the stream, particle size, velocity, and trajectory, and general characteristics of the spray forming processing. This system can provide physical data at reduced costs compared to generating the same data from a spray forming run.

To complete the modeling capabilities, the microstructure (grain size, precipitate, porosity, etc.) of spray formed aluminum alloys is being modeled to ensure desirable physical and mechanical properties. The technical approach is to couple transient heat transfer analysis with large deformation to simulate the flattening of metal droplets as they deposit onto the substrate at a high velocity and as the preform subsequently solidifies. This approach leads to an understanding of the deposition and growth of the deposit, including deformation of semi-solid droplets, dendrite fragmentation and grain multiplication, complete solidification, homogenization and coarsening, and the spatial distribution of these effects in the plane of spray along the direction of growth.

Conclusions

The Metals and Ceramic Processing Department has successfully applied spray forming techniques to a number of conventional and RSR aluminum alloys with a great deal of success. A number of different manufacturing processes are used to fully exploit the unique properties of spray-formed aluminum. Complete solutions to materials challenges are offered. The department has the resources to develop the processing parameters of an alloy, process and characterize the alloy, and also work with subcontractors to produce a finished component in the most economical and efficient way possible.

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4. Hummert, K.B., "New Aluminum Cylinder Liners for Combustion Engines Manufactured from Spray Deposited Billet Feedstock," *Proceedings of the Third Pacific Rim International Conference on Advanced Materials and Processing*, ed M.A. Imam et al. (Warrendale, PA: TMS 1998), pp. 3076-3086
5. Skinner, D.J., et. al., "Dispersion Strengthing Al-Fe-Si Alloys Containing V, Mn, or Cr," *Processing of Structural Metals by Rapid Solidification, ASM International* (1987), pp. 291-295.

Joining RAdm Paul Gaffney for a photo opportunity are (l-r) Lewis Watt, Deputy Director, iMAST; Persis Elwood, Chairman, JDMTP Sustainment/ Readiness Working Group; Admiral Gaffney; and Ted Hicks, iMAST's Navy program manager.

Lewis Watt shows General Langston an example of laser cladding capabilities resident within ARL's high energy processing facility.

iMAST's Lewis Watt talks shop with Admiral Frank Bowman, Director, Naval Nuclear Propulsion.

Mr. Al Lemanski, an Associate Director at iMAST, poses in front of ARL Penn State's AHS display booth with Dr. John Shaw, Chief Scientist, Boeing-Philadelphia.

iMAST hosts JDMTP Sustainment Working Group

To more clearly focus the ManTech Program on the requirements of the military sustainment and readiness enterprise, the Joint Defense ManTech Panel (JDMTP) established a Sustainment/Readiness Working Group (S/RWG). The S/RWG addresses critical repair processes, systems, and related manufacturing issues for DoD weapon systems programs. The establishment of the S/RWG recognizes the criticality of quality life-cycle support mandated by the extended operational life of currently fielded weapon systems. iMAST was privileged to host the most recent working group meeting. A highlight of the meeting was a visit and talk by the Chief of Naval Research, RAdm Paul Gaffney, USN.

DASN (RDA) tours iMAST

Brigadier General Edward Langston, USMC recently toured iMAST facilities at ARL Penn State as part of a continuing capabilities review of Navy and Marine Corps DoD technology resources. General Langston is Deputy Assistant Secretary of the Navy (Research Development & Acquisition) for Expeditionary Forces Programs. He assists The Honorable Lee Buchanan (ASN-RDA) in technical, programmatic, and doctrinal matters pertaining to Navy and Marine Corps expeditionary combat systems (land, sea, and air).

Navy League Expo

The annual Navy League Sea-Air-Space Exposition held in Washington, D.C. was once again an unqualified success. Significant industry participation drew large numbers of Navy and Marine Corps officials. This year's theme, "Power UP for 2000" focused on the idea that the future is increasingly complex and uncertain. By all standards, the year 2000 will serve as a benchmark against which both the past and the future will be measured. Since 1902, the Navy League has been educating Americans on the need for sea power, on and under the sea, in the air and out in space. The annual exposition provides a forum for the sea service professionals and the defense industry to come together. iMAST participated in the exposition for the second year in a row.

Annual American Helicopter Society Forum Hovers just North of U.S.

For the first time in its history, the American Helicopter Society (AHS) recently held its annual forum and technology display outside U.S. borders. The grand Canadian city of Montreal hosted the 55^{th} Annual AHS Forum. An appropriate theme, "Building Global Partnerships in the Next Millennium," drew large industry participation and guest speakers from all over the world. The forum provided an opportunity to communicate recent developments in the advancement and application of vertical flight technology throughout the U.S., Europe, and Asia. AHS Forum 56 will be held in Virginia Beach, Virginia, next May. For more information about AHS, call (703) 684-6777 or write Mr. Rhett Flater, Executive Director AHS, 217 N. Washington St., Alexandria, VA 22314 or e-mail: <ahs703@aol.com>.

CALENDAR OF EVENTS

9–13 Aug	Penn State Rotary Wing Technology Short Course	University Park, PA
16–18 Aug	4th ARO Workshop on Smart Structures	University Park, PA
13–15 Sep	4th Annual Conference on Spray Forming	Baltimore, MD
20–23 Sep	Marine Corps League Modern Day Marine Expo	Quantico, VA
21–22 Sep	NCEMT Modern Shipbuilding Technologies	Crystal City, VA
21–23 Sep	NDIA Combat Vehicles Conference	Fort Knox, KY
7–8 Oct	Electro-Optics Center Showcase	Kittanning, PA
17–20 Oct	8th ARO Workshop on Aeroelasticity of Rotorcraft Systems	University Park, PA
17–20 Oct	Penn State/ARO Workshop on Aeroelasticity of Rotorcraft Systems	State College, PA
24–27 Oct	AGMA Gear Expo ’99	Nashville, TN
26–18 Oct	AHS Rotorcraft Propulsion Specialist’s Meeting	Williamsburg, VA
Nov (TBA)	ARL Materials and Manufacturing Advisory Board Meeting	State College, PA
15–18 Nov	NDIA 3rd Annual DoD Maintenance Symposium	St Louis, MO
29 Nov–2 Dec	Defense Manufacturing Conference ’99	Miami, FL
6–9 Dec	NDIA 4th Annual Joint Services Hazardous Waste Management Conference	San Antonio, TX
27-30 Mar 2000	U.S. Army Ground Vehicle Survivability Symposium	Monterey, CA
2–4 May 2000	AHS Forum 56	Virginia Beach, VA
18–20 Apr 2000	Navy League Expo	Washington, D.C.

“Our biggest concern right now is cuts to the research and defense [R&D] budget. These 10 years from 1990 to 2000 will go down in history as the worst period of time in undermining our nation’s security.”

— Curt Weldon, R-PA, Armed Services Committee, April 1999